CRASH TESTING FOR REAL-WORLD SAFETY - WHAT ARE THE PRIORITIES FOR CASUALTY REDUCTION?

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ABSTRACT

The introduction of European legislative and consumer crash testing requirements in the late 1990s has resulted in marked changes in the design of vehicle structures and restraint systems. Crash tested vehicles in the range of New Car Assessment Programmes typically show reduced injury assessment values from the dummies and lower levels of intrusion, particularly in frontal impacts.

This paper examines real-world accident data to evaluate the changes that have taken place in car performance and the circumstances of injury in order to evaluate what new priorities there are in car occupant protection. Comparisons are made between older cars, built between 1991 and 1996 and newer cars, built up to 2000.The main conclusions are:-

- The rate of fatal driver injury in newer cars is 24% below that for the older cars;
- More car occupants now die in side impacts than in frontal impacts, 27% of these are seated on the far side of the vehicle;
- The numbers of fatalities in collisions with roadside objects virtually equals those killed in car to car impacts;
- The collision severities of fatal frontal impacts have not increased and there is little justification to raise crash test speeds;
- The collisions severities of fatal side impacts remain substantially above crash test speeds;
- Rear seat-belt use is low amongst fatally or seriously injured rear-seat passengers, this group is likely to receive the greatest benefit from belt reminder systems

BACKGROUND

The European Directive (96/79/EC) for frontal protection based on an offset deformable barrier crash test requirements was passed in December 1996. The Directive for side impact protection (96/27/EC) based on a mobile deformable barrier test had been passed in May 1996. The front and side impact protection requirements will apply to all new vehicles in Europe from October 2003. In the meantime the EuroNCAP consumer tests have been implemented using enhanced injury assessment criteria and modifiers based on the vehicle responses. The EuroNCAP frontal crash test is based on a 64 kph collision with the barrier, above the impact speed in the Directive, the side impact is at the same speed as the Directive. Injury assessment criteria in EuroNCAP are graded down to an equivalent 5% risk of injury for the highest levels of performance compared with a typical 50% injury risk within the Directives.

The first launch of EuroNCAP tested vehicles, in the small car category covered 6 models of car of which 1 attained only 1 star and the remainder 2 stars. In the most recent launch of Phase 11, in 2002, there were 18 models of which 4 reached 5 stars, 11 reached 4 stars and only 3 reached three stars. This corresponds to a dramatic increase in the overall levels of occupant protection as measured by EuroNCAP and in the year 2001 over 66% of new cars sold were 4 star vehicles with 25% 3 star vehicles.

To date over 200 cars have been assessed within the EuroNCAP programme and it is necessary to assess the degree to which the numbers of fatal and serious injuries have changed as a result of EuroNCAP as a measure of its real world success. A review of the crash conditions under which these injuries are sustained provides an indication of the benefits of further developments in the test procedures. This paper addresses both of these issues.

NATIONAL ACCIDENT TRENDS

The UK, like many other countries, maintains annual counts of the numbers of casualties in crashes. This data shows a steadily decreasing trend in car occupant fatality numbers since 1990 and is shown for the territories of Great Britain in Figure 1 against an index of 100 set for 1990. This shows that fatally injured car occupant numbers had declined by 30% by the year 2000.

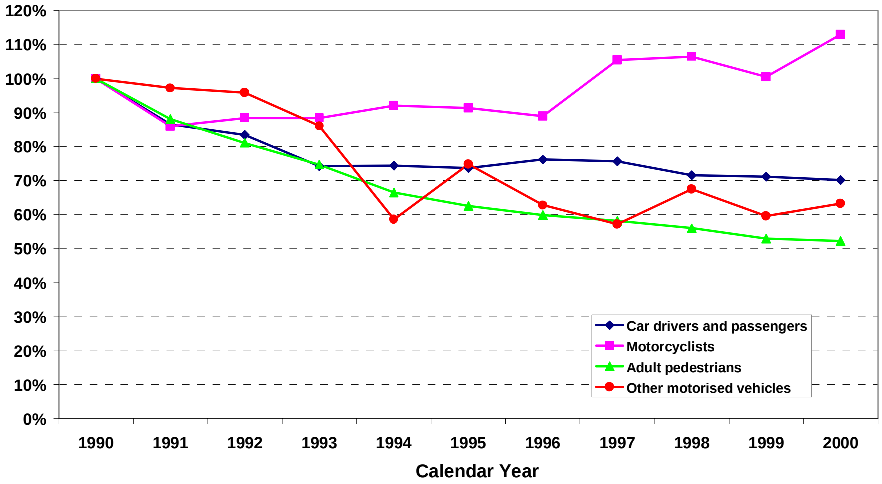

Figure 1. Trends in fatality reduction, 1990 – 2000.

Although motorcyclist fatalities had increased over the same period the numbers of fatalities in other motorised vehicles (trucks, buses, vans) and adult pedestrians had decreased to a greater extent. In this dataset injuries are classified according to whether they are fatal (died within 30 days), seriously injured (a fracture or an overnight hospital stay) or slightly injured.

These changes in fatality numbers are a consequence of a variety of factors that include improvements in vehicle safety but also include road safety measures, changes in driver behaviour, changes in patterns of vehicle use and increased use of vehicles. Indeed it is arguable that the road users showing the greatest decreases have had the smallest improvement in vehicle safety and that road safety measures have been very influential.

A more accurate assessment of the effects of improved vehicle design are observed by selecting the cars that were involved in crashes during a single year and examining the patterns in injury rates between cars of different design years. The GB data records uninjured drivers of vehicles but only records injured occupants in other seat positions, this makes it possible to calculate fatality and injury rates for drivers alone. Figure 2 shows the proportion of car drivers that were either killed or seriously injured in cars of each manufacturing year during 2001 while Figure 3 shows the equivalent distribution for fatalities alone. Cars built in the years 1991 to 1995 were classified as “older cars” while those built between 1996 and 2000 were classified as “newer cars”.

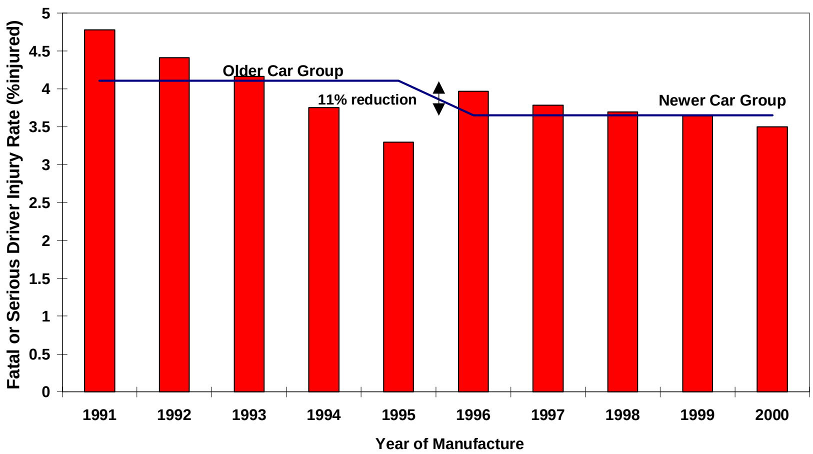

Figure 2. Percentage of drivers killed or seriously injured, 2001 crashes.

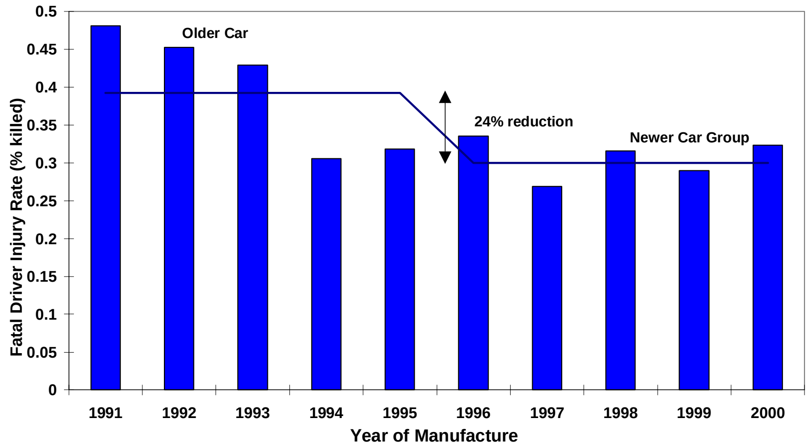

Figure 3. Percentage of drivers killed, 2001 crashes.

Cars manufactured in the period 1996 to 2000 showed a rate of driver serious or fatal injuries that was 11% below that of cars built in the first part of the decade. This substantial reduction was exceeded by the reduction in fatally injured drivers, shown in Figure 3.

The group of newer cars showed a reduction in fatality rate that was 24% below that of the older cars. The proportions of drivers that were killed reduced from 0.39% of the total driver population to 0.30%. Driver populations for each model year of car ranged between 14,345 and 23,186 and of the 1023 drivers that died in GB in 2001 there were 334 (33%) that were in vehicles manufactured before 1991.

The GB STATS 19 data includes an assessment by the police officer regarding the first point of impact on the vehicle, although there is some imprecision over the classification this can give an indication over the relative priorities. It should be noted that the low accuracy means that the data is not directly comparable with the detailed CCIS data, analysed in this paper.

Figure 4 shows the distribution of first point of impact for each model year represented in the 2001 data file.

The older cars, with manufacturing year from 1991 to 1995, showed an average of 61% of first impacts to the front of the car and 34% to the sides. The newer cars had a lower rate of front impacts (54%) but a higher rate if side impacts (40%). The average number of side impact fatalities rose from 22 to 26 per year in contrast to the number of front impact fatalities which dropped from 39 to 34 per year.

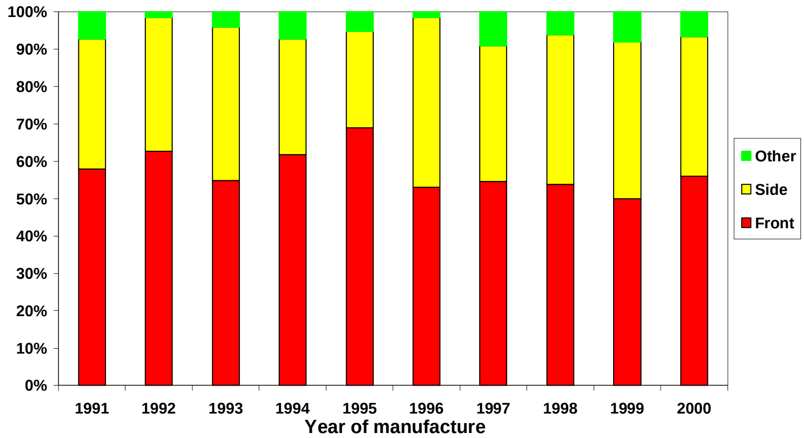

Figure 4. First Point of impact, 2001 crashes.

UK CO-OPERATIVE CRASH INJURY STUDY DATA

The UK Co-operative Crash Injury Study (CCIS) data is an in-depth sample of crash examinations conducted in a representative range of locations within the UK. A well controlled case selection procedure is utilised that ensures that all crashes investigated involve a vehicle, currently aged below 7 years old, that is towed from the scene of the crash and involves at least one injured occupant. The relationship between the crash sample and the regional crash populations are well defined. Full details of the procedures are available on the website (http://www.ukccis.org.uk).

The CCIS data covering crashes investigated during the period February 1996 to May 2002 were analysed and the cars selected were registered for use between 1991 and 2000. A total of 11181 sets of occupant details were analysed, of which 9582 had full injury data available and complete accompanying vehicle examination reports. The cases were divided into a group of "Older cars" manufactured between August 1991 and July 1996 (5170 casualties) and "Newer cars" manufactured between August 1997 and February 2001 (4412 casualties). The distribution of vehicle ages for the casualties is shown in Figure 5.

Occupants in the more modern cars who did not have a steering wheel airbag in front of them were generally seated in the passenger seats.

WHAT ARE THE OCCUPANT CHARACTERISTICS WHEN INJURIES DO OCCUR?

The characteristics and actions of occupants of each seat position can affect injury outcomes considerably. The high occupancy rate of the driver means that safety technologies are applied there first, correspondingly the rear seat positions tend to have the least advanced systems. Additionally driver characteristics such as age, gender or seat belt use can also affect injury outcome, particularly when protective systems are optimised for a small spread in user characteristics rather than the complete population.

Changes in Seat Position

Improvements in car occupant protection have been principally directed towards front seat safety. The EU Directive and EuroNCAP both use two adult front seat dummies but no adult rear dummies. Figures 6 and 7 show the occupant injury severities for each seat position for belted and unbelted occupants respectively.

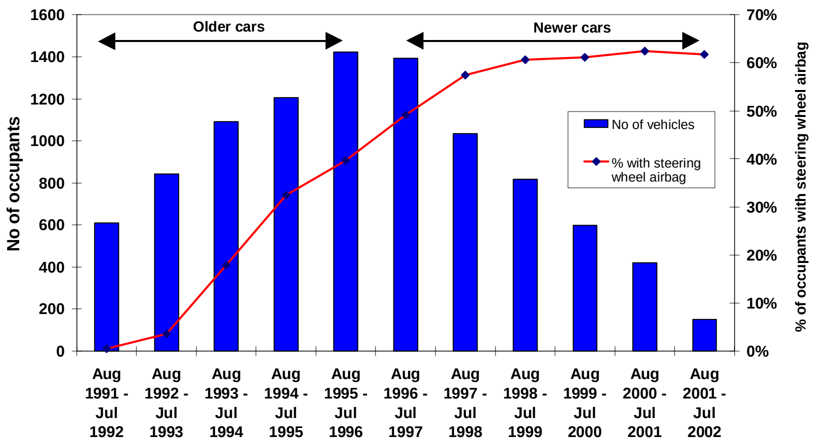

Figure 5. Ages of vehicles in CCIS sample.

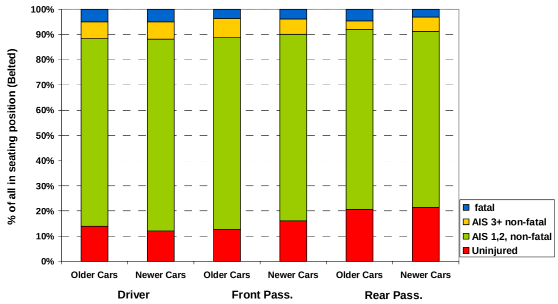

Figure 6. Injury severity: Belted occupants.

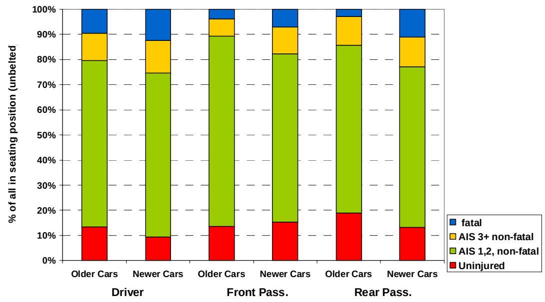

Figure 7. Injury Severity: Unbelted occupants.

The comparisons for belted occupants indicate no statistically significant changes in maximum AIS levels for occupants in each seating position. Overall belted front and rear passengers show marginally lower rates of injury in newer vehicles although the overall injury for drivers has increased. Closer examination shows that the percentage with fatal injuries has remained virtually unchanged for drivers and front passengers, it has decreased for rear passengers but this is not a statistically significant difference at the 5% level. Unrestrained occupants show a different pattern and in each case the rate of injury has increased in the newer cars. These changes are not statistically significant except for rear seat passengers where the injury rate increased from 81% to 87% and fatalities increased from 3% to 11%, ($\chi^2 = 9.5$, sig=2.4%, 3 degrees of freedom).

Changes In Occupant Factors

Restraint Use. The use of front seatbelts in the UK has remained high at over 90% since legislation in 1983. In 2001 the front seat occupant restraint use rate on the road was 92% and 59% for rear passengers. Figure 8 below shows the patterns of restraint use within the two age groups of car for occupants with all levels of injury severity. Belt use is determined by inspection of the restraint system for characteristic marks, in lower speed collisions the energies may be insufficient to leave these marks and in these cases belt use is unknown. A range of restraint usage rates is therefore shown for each group of car occupants to reflect this uncertainty.

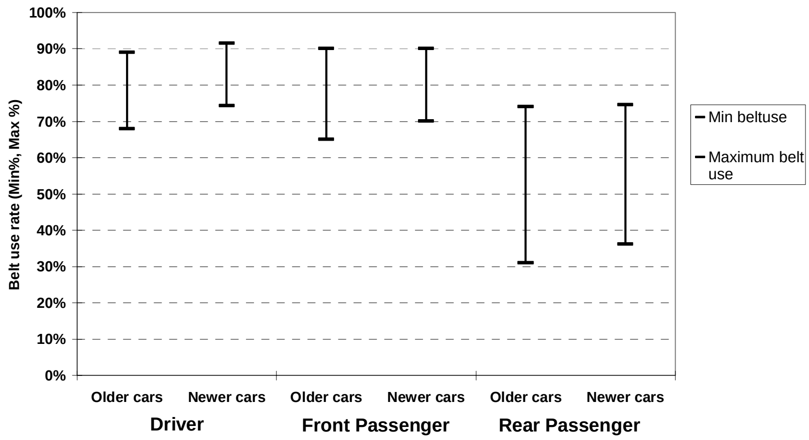

Figure 8. Seatbelt use, all casualty severities.

There was very little change in restraint use rates for each seating position between the two age groups of vehicle, with the levels for both front seat positions remaining between 70% to 90%. Rear seat restraint use was lower being between 30% to 75%.

In crashes unrestrained occupants are likely to be over-represented due to their increased injury risk and this is observed in the UK CCIS data of fatally injured casualties in Figure 9 overleaf.

Belt use rates amongst fatalities are maintained at levels broadly between 70% and 80% for front occupants, these levels are slightly below those for all severities of injury. The in-depth data indicates that the rates for rear seat occupants are reduced in the group of newer cars, falling from between 50%

and 75% to between 23% to 42%. Out of the total CCIS sample there were 483 casualties that sustained MAIS 3+ injuries in the newer vehicles and the numbers that were unbelted are shown in Table 1 below.

The number of unbelted rear occupants that were unbelted was between 31 and 40 while the comparable number of unrestrained front passengers was between 15 and 24.

Occupant Age. The regulation and design of restraints, seats and interior packaging is generally based around the needs of the 50%ile adult male occupant as represented by a mid-size male dummy. Nevertheless the vehicles in the crashes covered by the in-depth data have occupants with a wide range of characteristics. Figure 9 below shows the distribution of median ages of the occupants in each seating position together with the upper and lower quartiles. All are occupants of the newer cars.

The median ages of drivers and front passengers was similar at 36 and 31 years although front passengers exhibited a wider range of ages than drivers. Rear seat passengers were substantially younger with a median age of 17 years. Fatally injured occupants showed little difference in age distribution from occupants with all severities of injury except for front passengers, when fatally injured they had a median age of 52 years and an upper quartile of 64 years.

Table 1.
Numbers of unbelted occupants in newer cars with Maximum AIS >= 3

Seat Position	Belted	Unbelted	Unknown	Total
Drivers	244	57	40	341
Front Passengers	61	15	9	85
Rear Passengers	17	31	9	57
Total	322	103	58	483

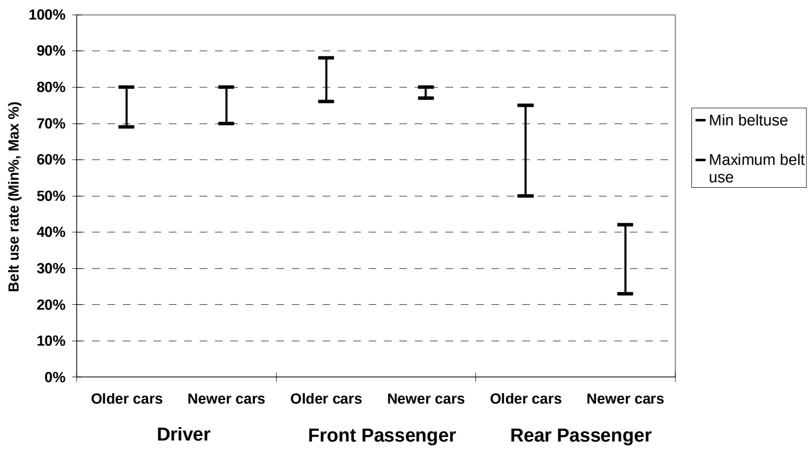

Figure 9. Seatbelt use, fatalities.

CHANGES IN CRASH CONFIGURATION

The Front and Side Impact protection Directives, introduced in 1996, came into effect at slightly different times and were interspersed with the first round of EuroNCAP testing. These tests had been preceded by rigid barrier offset frontal crash testing conducted in Germany. There is a question as to the degree to which the improvements in protection under the tested conditions also give improvements under other conditions so this section examines the CCIS data for any changes of the conditions under which life-threatening injuries are sustained.

Impact Directions

Impact direction is defined by the principle direction of force applied to the vehicle within the most severe impact, this is classified according to 90º intervals. The distribution for occupants with all severities of injury is shown in Figure 10.

The distributions show very little difference in impact direction between occupants of older and newer vehicles in crashes in which injuries of all severities are sustained. The dominant impact direction remains a frontal collision that is experienced by over 50% of occupants. The numbers of occupants experiencing side impacts remains similar at 10% – 12% and there are very similar proportions of casualties on the struck and non-struck sides.

When fatalities alone are examined substantially fewer casualties are observed in frontal collisions while struck-side occupants form a greater part of the group. Frontal impacts accounted for 53% of all severities of injuries but only 37% of fatalities in new cars. In contrast only 23% of casualties of all severities were injured in side impacts but this increased to 45% of fatalities, overall more casualties were killed in side impacts than in frontal impacts.

The proportion killed in frontal impacts decreased by 5% in the newer vehicles with an additional decrease of 3% in sideswipe collisions. In contrast the proportions killed as struck-side occupants increased from 27% to 33% in the newer cars. If improvements in the levels of protection applied equally to all impact directions then the distributions would be unchanged. The reduced proportions of frontal impacts and increased proportions of side impact indicate that protection has been differentially improved in frontal impacts compared with side impacts. This does not mean there has been no improvement in side impact protection but the amount of improvement in frontal collisions is not matched in side impacts. The priority impact direction for improvement in the newer group of cars remains the protection of both struck-side and non-struck side occupants.

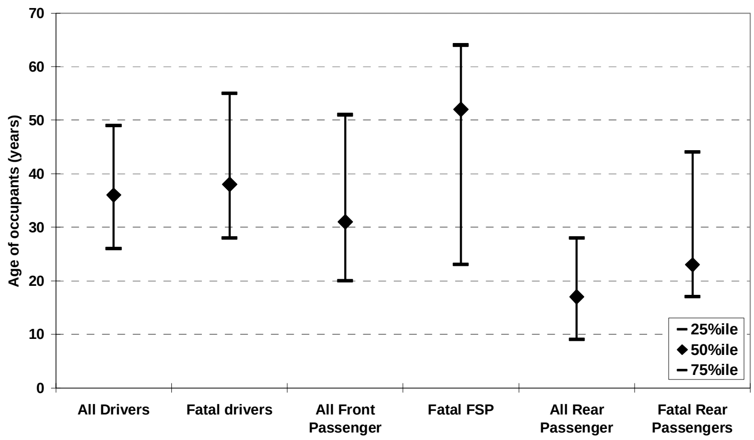

Figure 10. Ages of fatalities and all casualties.

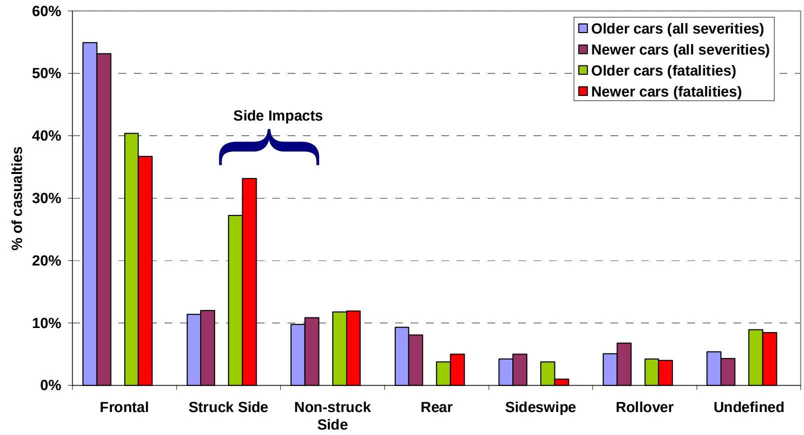

Figure 11. Impact directions, fatalities and all casualties.

What Are The Collision Partners?

Collision partners are classified by the nature of the striking object, the distribution is shown above in Figure 11.

The data shows some changes in the proportions of each impact direction between the older and the newer cars. The proportion injured in impacts with other cars has reduced by typically 8% while impacts with roadside objects have increased by 9%. Proportions in impacts with trucks or buses are unchanged between the two groups of vehicles.

In the group of newer cars, car-to-car collisions are the most common group of collisions when all casualty severities are examined accounting for over 50% of casualties. In comparison, impacts with roadside objects cause 25% of injuries and impacts with trucks or buses at 15%. The group of fatally injured occupants in newer cars shows a different pattern. 35% are killed in impacts with cars while 33% are killed following a collision with a roadside object, usually a tree. Collisions with trucks or buses account for a further 27% of fatalities in newer cars.

This data indicates that the levels of protection in car-to-car collisions have increased more than in collisions with other collision partners.

Collision Severities

The CCIS is a retrospective crash investigations study that examines damaged vehicles a few days after the crash to take advantage of the efficiencies of retrospective sampling. Skid marks and other traces that are often used to calculate collision severities are therefore unavailable so the Study has to utilise damage based methods of calculation. Nevertheless the accuracy of these methods is well documented for modern vehicles (Lenard et al, 2000) and they have been shown to under-estimate frontal delta-v by between 5% and 10% in frontal collisions and by 6% in side collisions. The same methods were used to estimate delta-V in frontals collisions and impact speed in side collisions within the CCIS case material. The median and quartile delta-V in frontal impacts is shown in Figure 12 for casualties of all severity, casualties with MAIS 3+ injuries and for fatalities. The median values are shown together with the quartiles.

Figure 12 indicates that the collision severities in which occupants of newer cars are injured are typically slightly below those for the older designs of vehicle. The median delta-V for all casualty severities was 33kph in older vehicles compared with 30kph in newer vehicles. Amongst fatalities it was 60kph in older vehicles against 53kph in newer cars. This does not indicate that the levels of frontal protection have decreased so that more injuries are sustained at lower collision severities, indeed it might be anticipated that the median delta-V might increase as protection levels are raised for lower severities. Instead the above analysis has indicated that there are other characteristics of the crash that have changed in priority in response to improved levels of crash protection in the current range of European crash conditions.

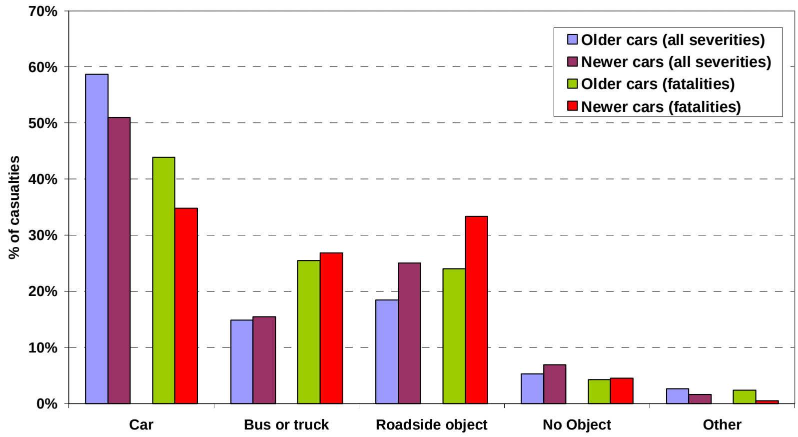

Figure 12. Collision partner, all casualty severities and fatalities.

Figure 13 compares the typical delta-V in frontal collisions with the conditions of the EU frontal impact Directive and the EuroNCAP test condition. The impact severity of the Directive, at 56kph, is above the median delta-V for casualties of all injury severities and for those with an MAIS of at least 3. The EuroNCAP severity at 64kph is now above the 75%ile of the group of fatalities. Only 15% of fatal casualties in frontal impacts experienced delta-V above 64kph in new cars compared with 44% in older cars.

Side Impacts

Delta-V is less of a relevant measure of collision severity in side impacts so the impact speed was calculated within the CCIS data, still using damage based methods. The range of impact speeds for struck-side occupants is shown in Figure 14.

Impact speeds for each level of injury changed only marginally between older and newer cars but in all cases the median severity slightly increased. The overall pattern remained unchanged.

In contrast to the situation for frontal impact the crash test speeds of both the Directive and EuroNCAP can be seen to be low compared to the crashes where life-threatening injury is sustained. Amongst newer vehicles the impact speed of the test conditions is slightly above the median values of crashes where all severities of injury are sustained at 51kph while the median severity experienced by casualties with MAIS 3+ injuries was 55kph. Fatal injuries were sustained substantially above the test speeds and only 15% of those struck side occupants that died in newer cars experienced collision severities below that of the test conditions.

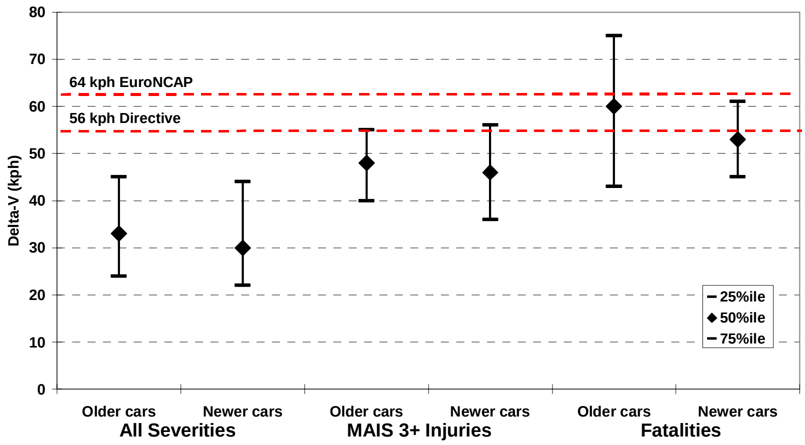

Figure 13. Delta-V in frontal collision – restrained occupants.

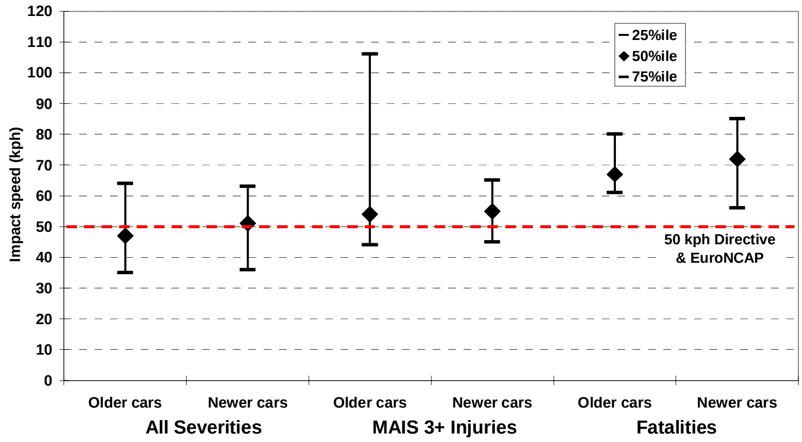

Figure 14. Impact Speed in Side Collisions.

DISCUSSION

National accident data provides a general overview of trends and priority areas and in the GB data it demonstrates a steadily decreasing number of car occupant fatalities that fell by 30% over the decade. This decrease is a result of vehicle safety changes, road safety improvements, changes in road user behaviour such as drink/drive and increased use of cars. The precise part that is due to improvements in vehicle safety cannot be determined using the available data but the 24% reduction in driver fatalities in the newer cars indicates that a large portion of the saving is due to vehicle safety measures. This demonstrates the casualty reduction potential of vehicle based passive safety measures against the background of a well-developed road safety infrastructure. Much of this improvement is coincident with the increased crash protection requirements of the Directives and the UK Government initiated EuroNCAP and these have to be seen as a major driving force in the safety improvements.

The analysis of the CCIS data showed little change in the rates of injury for belted occupants in newer cars compared with the older car group. This apparently contradicts the view that car design has increased the levels of protection available. Previous research conducted using the CCIS database (Kirk et al, 2002, Frampton et al, 2002) has demonstrated that injuries to the head and face have markedly reduced as a result of airbags and improved restraint systems, however there have been no changes in injury rates to other body regions and both chest and lower extremity injury rates have remained virtually unchanged. Assessments of overall injury severity, such as the Maximum AIS or the national police injury severity, will not reveal the detailed reductions in particular injuries that have taken place.

The statistically significant increase of injury rates for unbelted rear seat occupants with any severity of injury is unexpected and requires closer examination before it can be understood more fully. Restrained rear seat occupants have not historically been exposed to intrusion related injuries in older cars in frontal collisions so improvements in front end structure will not automatically provide an injury reduction benefit. Any increase in stiffness may increase deceleration levels and these are likely to affect unrestrained passenger injuries, alternatively an increase in front seat stiffness as part of a package to reduce soft tissue neck injuries may also serve to increase rear seat occupant injury rates. A closer scrutiny is required before any of these possibilities can be confirmed.

The levels of seatbelt use in Europe are frequently assumed to be high in comparison with levels in the US and different philosophies have developed in response to this. The US regulation still retains a requirement for inflatable restraint systems to provide some protection for unrestrained occupants of cars under FMVSS 208. There is no consistent measure of seatbelt use for the EU as a whole but in 1996 the European Transport Safety Council estimated the level was 80% (ETSC, 1996). In the US front seatbelt use is now 75% (NHTSA, 2002). Nevertheless the EU does not formally have a requirement for any protection of unbelted front occupants either as part of a Directive or within EuroNCAP. Instead the approach has been to encourage increased use of seatbelts using seat belt reminders. These are systems intended to increase the levels of belt use in cars by raising the awareness of the driver to unrestrained occupants in the car using visual and auditory signals. Additional encouragement of course will also derive from the nature of enforcement of the regulations in member states.

The CCIS data analysed in this paper demonstrates that unrestrained car occupants still form a significant part of the fatal injury group, even in a high restraint use territory such as the UK. Between 12% and 20% of the occupants of newer cars that sustained MAIS 3+ injuries were unbelted drivers and this highlights the need for measures to increase driver seatbelt use. However in the UK data there were more unbelted casualties with these injuries seated in the rear seats than in the front passenger seats and it has to be considered that in the UK there would be greater casualty reduction as a result of seat belt reminder systems in the rear seating positions than in the front passenger seats. In the most recent EuroNCAP test launch, number 11, there were 18 vehicles tested and of these 9 were fitted with seatbelt reminder systems. None had systems that were operational in the rear seating positions. It is anticipated that all territories would show the greatest numbers of unrestrained occupants to be drivers and these must remain the priority.

The distribution of occupant ages for each seating position identifies the need for restraint design to take account of the specific needs of the seat occupants. In newer designs of car front seat passengers tend to be substantially older than those in the rear seats. With a median age of 50 years front passengers are frequently within the age groups likely to be affected by osteoporosis, particularly those that are killed in crashes. The design of restraints for this group does not appear to be clearly based on the needs of the more vulnerable car occupants.

The changes in the direction of crashes for those that died indicate the success of the EuroNCAP programme to improve frontal crash protection. The proportion of fatalities that were involved in frontal collisions fell by 8% with a corresponding increase in side impact proportions. The opportunities for improved side impact protection are inherently lower than in frontal impacts due to the more restricted space available for countermeasures. Nevertheless the newer vehicles did not exhibit the same degree of improvement in side impacts as in frontal collisions and, with more fatalities in side impacts than in frontal impacts, side impacts now take a higher priority. In particular the reduction of injuries to non-struck side occupants remains an important, unaddressed, issue of side impact protection. In newer cars, 26% of all side impact fatalities were seated on the non-struck side, confirming the earlier results of Frampton (Frampton et al, 1999).

The improvement in side impact protection may be lower than expected as a result of the crash speeds involved in fatal collisions. The 50 kph impact speed of the test procedures is lower than nearly all fatal casualties experienced and below more than half of MAIS 3+ casualties. The Preliminary Regulatory impact analysis for FMVSS 214 (NHTSA 1988) identified that the median impact conditions for serious injury crashes had the target car travelling at 17.5 mph and the bullet car at 35 mph. Other studies have repeated these results that were summarised in the review of the EU Front and Side Impact Directives (Edwards et al). New technical solutions may now be available to address this significant part of the road casualty problem either by improving passive protection or by new technical active safety measures.

In contrast the collision severity in the frontal crash tests was more typical of the delta-V assessed in fatal collisions. The median delta-V for MAIS 3+ frontal collisions was 46 kph in the newer cars, slightly below that of the severity of the EU Directive while only 15% of fatally injured occupants were in collisions with a higher severity than the EuroNCAP test condition. These collision severities are known to be under-estimated by 5% - 10% so the in-depth crash injury data gives little indication that frontal crash test severities need to be raised. This conclusion is in some ways counter-intuitive since it might be anticipated that an outcome of the EuroNCAP frontal test would be to prevent fatalities at all lower speeds leaving only those killed in higher severities. Instead the crash injury data identifies that the risk of fatalities has decreased in those crashes represented by the test and that the remaining group is different from the test in other ways such as the nature of the collision partner.

SUMMARY

The improvements in vehicle safety that have occurred as a result of the EuroNCAP consumers tests and the Front and Side impact Directives have resulted in major improvements in the safety of cars, reducing the risk of fatal injury by 24%. There are still opportunities to increase the levels of protection further by the mitigation of higher speed side collisions and improving the protection in impacts with roadside obstacles.

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CCIS is operated by teams from the Birmingham Automotive Safety Centre of the University of Birmingham; the Vehicle Safety Research Centre of Loughborough University; the Vehicle Inspectorate Executive Agency of the DfT and TRL Limited. Further information on CCIS can be found at http://www.ukccis.com/.